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TARGET DETECTION AND RANGE ESTIMATION

James A. Caviness, et al

Human Resources Research Organization

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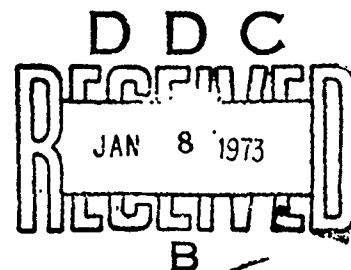
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Target Detection and Range Estimation

James A. Caviness, Jeffery L. Maxey, and
James H. McPherson

HUMAN RESOURCES RESEARCH ORGANIZATION
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13. ABSTRACT <p>A study of target detection times for human targets in various field situations was conducted to obtain data for the Army Small Arms Requirements Study (ASARS). Three significant variables--terrain complexity, target speed, and target distance--and two randomized control variables (direction of movement and starting position) were studied. Results indicate that terrain complexity and target range were positively related to detection time; target speed was negatively related. Examination of the 24 detection-time distributions suggests that the underlying probability distribution for the detection-time distributions was not exponential in form.</p>		

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**James A. Caviness, Jeffery L. Maxey, and
James H. McPherson**

**HumRRO Division No. 4
Fort Benning, Georgia**

HUMAN RESOURCES RESEARCH ORGANIZATION

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The Human Resources Research Organization (HumRRO) is a nonprofit corporation established in 1969 to conduct research in the field of training and education. It is a continuation of The George Washington University Human Resources Research Office. HumRRO's general purpose is to improve human performance, particularly in organizational settings, through behavioral and social science research, development, and consultation. HumRRO's mission in work performed under contract with the Department of the Army is to conduct research in the fields of training, motivation, and leadership.

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

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FOREWORD

This report describes research on target detection conducted by the Human Resources Research Organization as a Technical Advisory Service. The objective was to provide data on times for target detection, and errors in range estimation, using infantry targets in field situations. These results were presented to the Army Small Arms Requirements Study, Phase II (ASARS II) and are now being published to make them more generally available to the military and scientific community.

The research described in this report was conducted by HumRRO Division No. 4, Fort Benning, Georgia, under the direction of Dr. T.O. Jacobs, Division Director. Research was performed by Dr. James A. Caviness and Mr. Jeffery L. Maxey.

Military support was provided by the U.S. Army Infantry Human Research Unit, under the command of LTC Chester I. Christie, Unit Chief. The Project Officer at the Human Research Unit was 1LT James H. McPherson, and the military research assistants were SP5 Thomas F. McCoy, PFC Rodger W. Griffeth, and PFC Patrick A. Devine.

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Meredith P. Crawford
President
Human Resources Research Organization

SUMMARY AND CONCLUSIONS

MILITARY PROBLEM

The U.S. Continental Army Command has requested data on target detection times, obtained by using infantry subjects and human, moving, infantry-type targets. These target detection data are needed for comparison with predictions from a target detection model generated by ASARS II from data provided by the Tank Weapons System studies.

The Army Small Arms Requirements Study (ASARS) is a study group of the Army Small Arms Program that has as its overall goal the development of the optimal weapon for the infantryman. ASARS was set up in two phases, with the main objective of the first phase being the preparation of a methodology for the conduct of the second phase. ASARS I is now complete, and ASARS II is under way. It is essentially a computer simulation of Infantry in defense and attack. The objective is to document the variable and interacting characteristics of weapons needed to satisfy small arms requirements now and in the future, and to establish the capability for performing trade-offs of each of these characteristics in terms of combat effectiveness.

The ASARS II computer simulation has a subroutine that determines whether an observer is able to visually detect a non-firing target by visual search during a given event. This subroutine is based upon a target detection model developed during the Tank Weapons System studies. This model describes the distribution (negative exponential distribution) of the times required by a single observer to detect a particular target, and indicates that time to detection is related to terrain complexity, range, and crossing velocity. The present study is an attempt to validate the work of the Tank Weapons System studies for human targets.

RESEARCH PROBLEM

The present research was designed to determine whether a negative exponential distribution of detection times was adequate for describing the detection of moving human targets by human observers, and whether the detection behavior of stationary observers searching for a moving human target was affected by (a) speed of the target, (b) range of the target, and (c) denseness or complexity of the terrain in which the target appeared.

In addition, data on errors in range estimation were collected. In view of a generally acknowledged need for a broad base of information on the infantryman's ability to estimate ranges, a secondary goal of this research was to provide data on range estimations made by the subjects in the target detection experiment.

APPROACH

Three levels for each of three significant variables (terrain complexity, target speed, and target distance) were investigated, using a $3 \times 3 \times 3$ factorial design that tests the major effects and interactions. In addition, two control variables (direction of movement and starting position) were randomized.

The subjects were required to detect the targets and to estimate their ranges. Descriptive statistics were collected from 90 subjects, making a total of 810 observations.

RESULTS

The overall average error in range estimation was 59.6 meters (with a standard deviation of 77.4 meters), and the overall mean detection time was 3.8 seconds (with a standard deviation of 4.4 seconds). Only 79% of the targets were detected.

The analysis of variance showed that all main effects and interactions (of terrain complexity, target distance, and target speed) were significant at the $p < .01$ level.

An analysis for exponentiality of the detection time data led to the rejection of the hypothesis that the underlying probability distribution was the negative exponential distribution.

CONCLUSIONS

The data reported show that, over all conditions, the average error in range estimation deviates from doctrinal limits (10%). As range increases, accuracy (defined as the inverse of average error) and precision (defined as the inverse of variance) decrease.

The ability to detect human targets is significantly affected by the target's speed, the target's distance from the observer, and the complexity of the background in which the target appears. As the terrains studied became more complex, or as the magnitude of the target-to-observer range increased, the magnitude of the detection times increased. However, as the target's speed increased, these times decreased in magnitude. Therefore, terrain complexity and target range were positively related with the time to detection, while target speed was negatively related with the time to detection.

Examination of the 24 detection time distributions¹ suggests that the underlying probability distribution for the detection time distributions obtained in the present study was not exponential in form. As a consequence, it would appear that the prediction of detection times based upon the Tank Weapons System model of detection is not appropriate for the detection of human moving targets.

¹ For the three experimental conditions of high terrain complexity, 300 meters, and the three target speeds, no observers detected the moving human target, so no detection time distributions were obtained.

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Target Detection and Range Estimation

INTRODUCTION

A study of target detection times for human targets in various field situations was conducted by the Human Resources Research Organization at the request of the U.S. Continental Army Command (CONARC). The research, performed during the fall of 1970, was in support of the Army Small Arms Requirements Study (ASARS).

The ASARS group had identified a weakness in their data base: a lack of empirical data on target detection rates under varying conditions of environment, target characteristics, and observer characteristics. These target detection rates were collected by HumRRO under the variables mentioned, and range estimation data were derived as a by-product of the research.

GENERAL SIGNIFICANCE

What are the significant variables that affect the detection of enemy targets by infantrymen with given training backgrounds? How do the significant variables differentially affect the detection of enemy targets? These two questions form the core of an important problem: What determines the adequacy or inadequacy of the infantryman's detection performance in the battlefield situation?

For a given battlefield environment, the infantryman may be engaged in one of two missions. The mission may be one of *defense*, in which case the task is to defend an area from penetration and capture; or, the mission may be one of *offense*, in which case the task is to find and destroy the enemy. In order to succeed in either of these missions, the infantryman must be able to determine whether the enemy is present in his vicinity—that is, he must be able to detect enemy targets. Those who supervise the infantryman in the battlefield of today hold the opinion that he is not able to detect enemy targets as well as is needed, but there is no exact information on what determines the infantryman's detection performance.

There are several compelling reasons for wanting to know what determines target detection performance. This knowledge is needed for the development of tactical doctrine and weaponry, and for application to the processes of selection and training.

PRIMARY UTILIZATION

Given an adequate data base, decision making can be exercised in a computer simulate, as in the ASARS simulation BATTLEQUEEN. BATTLEQUEEN has a subroutine that determines whether an observer is able to visually detect a non-firing target by visual search during a given event. This subroutine is based on a target detection model developed during the Tank Weapons System studies (1,2). This model describes the distribution of the time required by a single observer to detect a particular target (a tank) from among those present in his environment, after the target has become intervisible (i.e., an unobstructed line of sight exists between the target and the observer).

Stollmack (3) showed that the probability of the detection of a tank was described by the uniform negative exponential distribution. However, it was thought that the Tank Weapons System study formulation of target detection function might not be directly

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applicable to ASARS because of the obvious differences between human and tank targets. The present study attempted to validate the work of the Tank Weapons System studies for *human* targets. Detection time data were collected for single observers who were searching for single human targets under various conditions of range, terrain complexity, and crossing velocity.

OTHER UTILIZATION

Data generated in this experiment will be used to broaden the data base of other target detection and range estimation research. A review of literature shows little in the area of detection of moving human targets. Furthermore, of the studies reported, most were conducted with other than infantry targets and none examined the movement variable when infantry targets were used. For example, Dobbins and associates (4, 5) and Strauss and DeTogni (6) used infantry targets, but not with movement. An annotated bibliography of these and other studies is contained in Appendix A.

METHOD

DESIGN

The design of the experiment conformed to a $3 \times 3 \times 3$ mixed factorial with three levels of terrain complexity (low, medium, and high) as the between-subjects variable. The two within-subject variables were the range at which the target initially appeared (100, 200, or 300 meters) and the speed at which the target moved (walk, slow run, and fast run).

SUBJECTS

The subjects for target detection and range estimation were 90 male, junior enlisted men. All subjects were Basic Combat Training (BCT) graduates, none had ever been assigned outside the Continental United States (CONUS), and all except six were graduates of an Advanced Individual Training (AIT) program. The goal in selecting subjects was to approximate the response of the inexperienced combat rifleman.

For judging terrain complexity, the subjects were 36 Vietnam veterans with varied combat experience.

TARGETS

Three enlisted men were used as the targets in the experiment. They were dressed in fatigue jackets and trousers, black combat boots, and utility caps with bill (Figure 1). The fatigue jackets were painted with brown and green in a camouflage pattern. Green and brown camouflage make-up was used to cover exposed skin.

Prior to the experiment, the targets were given training in moving at the various speeds (walk, slow run, fast run) called for in the experiment. They were also familiarized with the test areas and especially with their assigned areas of operation as targets. A pilot study also was run to give the targets experience.

Targets



Figure 1

TERRAIN

The test areas used in the experiment were found in the Malone complex of ranges at Fort Benning, Georgia. Malone 2 and 3A were selected because they met the requirements of low, medium, and high terrain complexity. One test area was lightly vegetated and offered little concealment; it was covered with tall grasses and a few small pine trees (Figure 2).

A second test area was heavily covered with tall grasses and was more grown over with bushes and larger pines; concealment was more plentiful (Figure 3).

A third range was heavily overgrown, with ample concealment; tall grasses and bushes abounded and there was a mixture of large pine and deciduous trees. The rolling terrain was a contrast to the relatively flat areas in the other two test areas (Figure 4).

On all three areas, target presentation areas were constructed at 100, 200, and 300 meters. The area of observation extended out beyond 300 meters, and subtended an angle of 30° (Figure 5). The limits of the area of observation were clearly marked at all three test areas.

Low Terrain Complexity



Figure 2

Medium Terrain Complexity



Figure 3

High Terrain Complexity



Figure 4

EQUIPMENT

In order to record the detection times of the subjects electronically, the three terrain areas used in the experiment were wired, with switches down range to activate an electric clock and a switch at the observation point to deactivate it. The three areas were wired almost identically. The areas were set up, as previously stated, with a depth of 300 meters from the observation point and subtending an angle of 30° . A 300-meter length of wire was placed down the centerline (0.0°) of the field. Wire was laid at right angles from the centerline out 15° to the left and right along the target presentation areas at 100, 200, and 300 meters.

There were nine possible starting positions. The switches that started the clock were placed at 0.0° , 7.5° left of centerline, and 7.5° right of centerline at 100, 200, and 300 meters. The target was required to press a switch at whichever starting point he began his run. This opened the circuit and the clock started. Another "push-type" switch was in the hand of the subject, who pressed it when he detected a target. A time could then be read from the clock. The clock was electric and accurate to 0.1 second.

Communication between the targets and the control point, from which they received their instructions, was provided by PRC-88 radio sets. Sound-powered telephones were the link between the experimenter at the observation point and the experimenter at the target control point.

A typical sequence of operation began with the control point contacting a target with the PRC-88 radio and giving the target instructions on where and how fast to move. The target then pressed the switch at his starting point, actuating the clock, and began his run. The subject started his visual search and, when he detected the target, pressed the switch at the observation point, stopping the clock.

Terrain Diagram

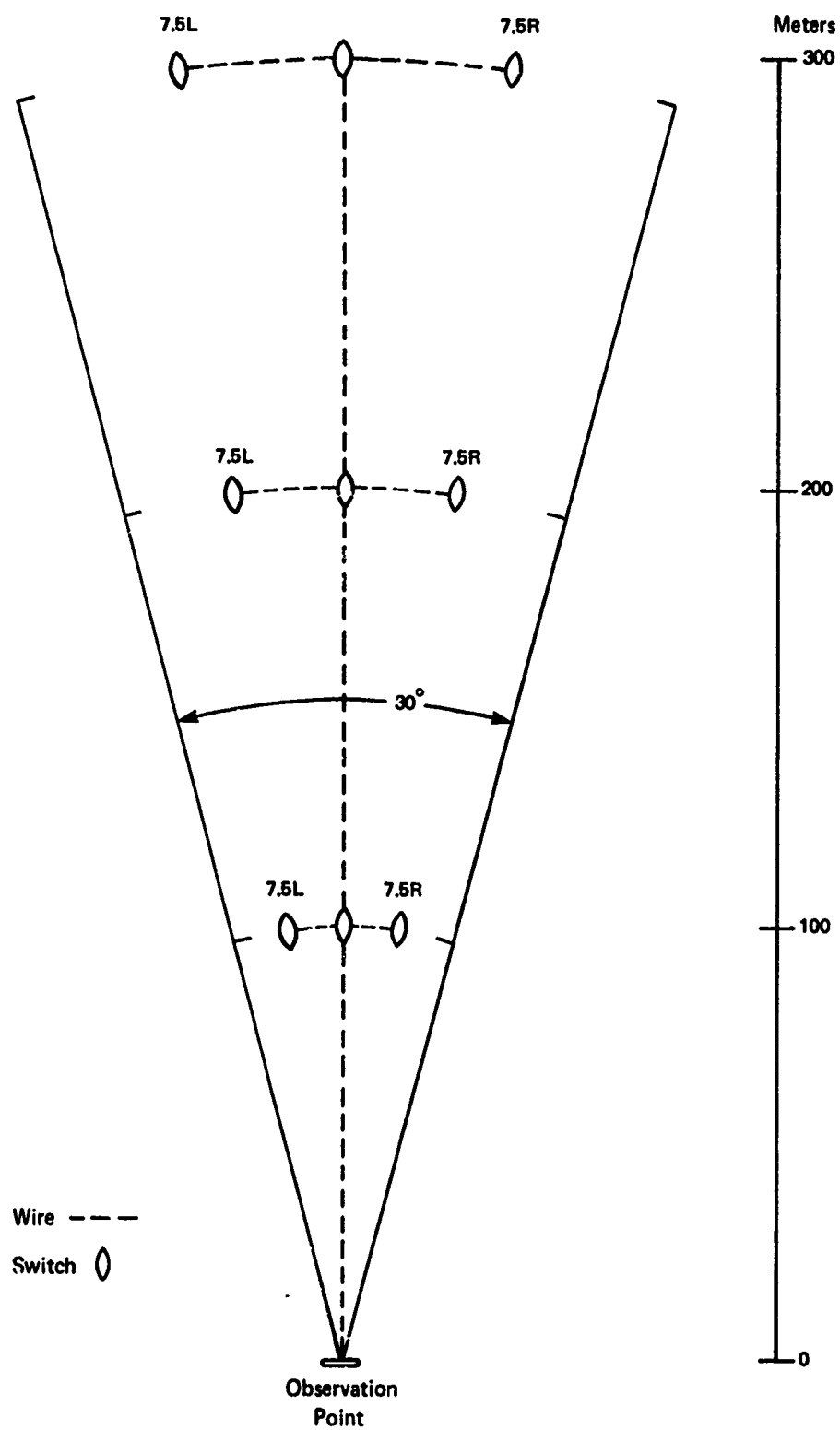


Figure 5

PROCEDURE

Upon arrival at the testing site, the subjects were seated in an area away from the observation point. The test administrator gave each subject a pencil and a biographical information form (Appendix B) and explained instructions for filling out the forms. Each subject was assigned the number that was printed on his data form, and was required to give the following information: name, rank, social security account number (SSAN), age, time in service, experience (e.g., Basic Combat Training, Advanced Individual Training, Noncommissioned Officer Candidate Program, Officer Candidate School, combat), and previous areas of assignment.

When all subjects had completed the data forms, the administrator read the instructions for participation in the experiment (Appendix C). After all questions had been answered, the subjects were moved into a holding area near, but not in sight of, the observation point. An NCO made certain that the men remained in numerical order.

The experimenter controlling the targets moved them to the proper starting points for the first observer. The experimenter at the observation point called for the first subject. When he arrived, the experimenter filled in the subject data sheet (Appendix D), and indicated the sector of search. The subject stood on the observation point holding his hand switch; a target was then told to begin his run and the subject was told to begin his search (Figure 6). After the subject detected the target and pressed his hand switch, stopping the clock, he was instructed to turn, face the experimenter, and give an estimate of the target range. The experimenter entered this estimate on the subject data sheet along with the detection time. When the target was in position for the next run, the subject turned around and repeated the detection and range estimation procedure.

Subject (Left) and Experimenter (Right)



Figure 6

Each subject was given an opportunity to make nine observations and range estimations with all targets (100, 200, 300 meters) appearing three times. If a subject detected a target, he was required to estimate the target's range at the time of detection; if he did not detect a target, he did not make a range estimate. The order in which the targets were presented was randomized to prevent a learning effect.

Upon completion of nine trials, the subjects were sent to an area away from the observation point and the pretest holding area.

The 90 subjects used for target detection and range estimation were separated into 30-man groups, and each group was assigned to one of the three test areas (Nos. 1-30 to Area 1, 31-60 to Area 2, 61-90 to Area 3).

The 36 men used in judging the terrain complexity of the three test areas were randomly divided into 12 groups of three men. The test areas were presented in a random order to each group. They were given forms (Appendix E) on which they rated the complexity (i.e., difficulty of target detection) of the areas, rating each area on a continuum of seven points running from "very easy to detect" through "impossible to detect." As they entered the test areas, the members of each group were briefed on the limits of observation and how to mark their forms. Each group stood on the same observation point as the subjects in the target detection section of the experiment.

RESULTS

TERRAIN COMPLEXITY JUDGMENTS

Thirty-six subjects judged the complexity of the three terrains by rating each field on a scale of one (low) to seven (high). The low complexity field received an average rating of 2.72 with a standard deviation of 0.74. The medium complexity field received an average rating of 4.31 with a standard deviation of 0.94. The high complexity field received an average rating of 4.94 with a standard deviation of 0.98. These data are summarized in Table 1 and graphed in Figure 7.

Table 1

Terrain Complexity

Terrain	Number of Observations	Average Rating (\bar{X})	Standard Deviation (SD)
Low Complexity	36	2.72	.74
Medium Complexity	36	4.31	.94
High Complexity	36	4.94	.98

RANGE ESTIMATION

Over all conditions, the average absolute (\bar{x}) error² in range estimation (for the targets detected) was 59.6 meters with a standard deviation (SD) of 77.4 meters. The distribution of absolute errors in range estimation over all conditions, is presented

² Absolute error (AE) was defined as the difference between the actual range (AR) at which the target appeared and the estimated range (ER) at which the target appeared disregarding the algebraic sign of this difference (i.e., $AE = |AR - ER|$).

Distribution of Terrain Complexity Judgments

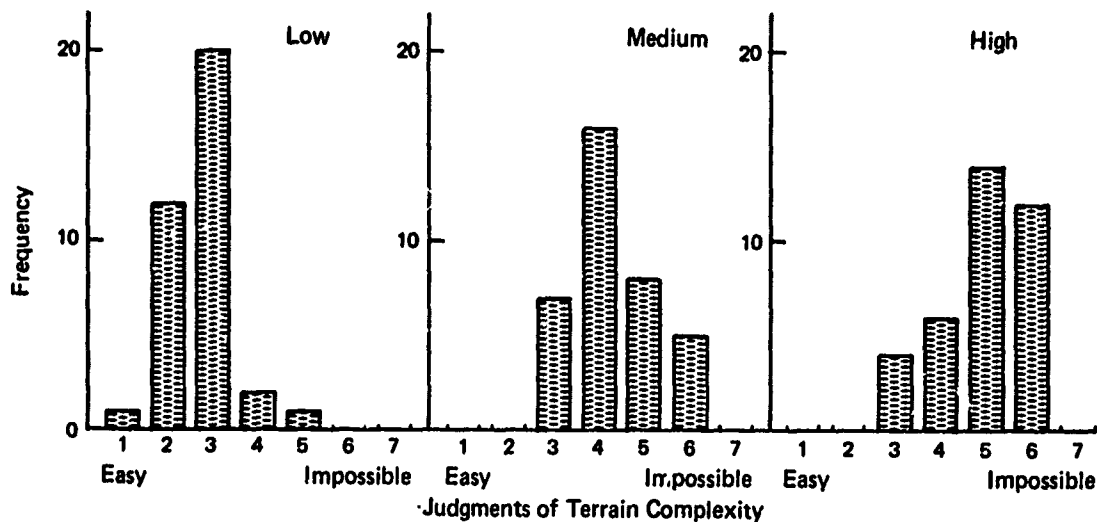


Figure 7

graphically in Figure 8. Note the size of the largest errors; it is possible that some of these judgments were not made in good faith. In order to mitigate the effect of these few extreme estimations on the measure of central tendency and the measure of variability, the median and interquartile range were computed as supplements to the mean (average, \bar{x}) and the standard deviation (SD). The median (Md) was 50 meters and the interquartile range (IQR) was 75 meters.

By terrains, but over all other conditions, the average absolute error in range estimation for low terrain complexity was 64.4 meters with a standard deviation of 98.9 meters, for medium terrain complexity it was 54.5 meters with a standard deviation of 60.6 meters, and for high terrain complexity it was 59.6 meters with a standard deviation of 56.8 meters. For low terrain complexity, the median was 25 meters and the IQR 60 meters; for medium complexity, the median was 50 meters and IQR 35 meters; for high complexity, the median was 50 meters and IQR 80 meters.

By distances, but over all other conditions, the average absolute error in range estimation for 100 meters was 38.1 meters with a standard deviation of 44.6 meters, while the median error was 25 meters with an IQR of 40 meters. For 200 meters, the average error was 69.9 meters with a standard deviation of 69.2 meters, while the median error was 50 meters with an IQR of 75 meters. The average error for 300 meters was 77.7 meters with a standard deviation of 116.9 meters, while the median error was 50 meters with an IQR of 100 meters.

By target speed, but over all other conditions, the average error in range estimation for walking (1.5 meters/second) was 68.0 meters with a standard deviation of 89.6 meters, while the median error was 50 meters with an IQR of 75 meters. The average error for slow running (2.7 meters/second) was 53.9 meters with a standard deviation of 55.9 meters, while the median was 50 meters with an IQR of 85 meters. For fast running (7.5 meters/second), the average error was 56.8 meters with a standard deviation of 73.9 meters, while the median error was 50 meters with an IQR of 55 meters.

The range estimation results are summarized in Table 2, in which various subdivisions of data can be studied (e.g., average error of range estimation in a low complexity terrain at 100 meters when the target moved out at a walk.)

Distribution of Errors in Range Estimation

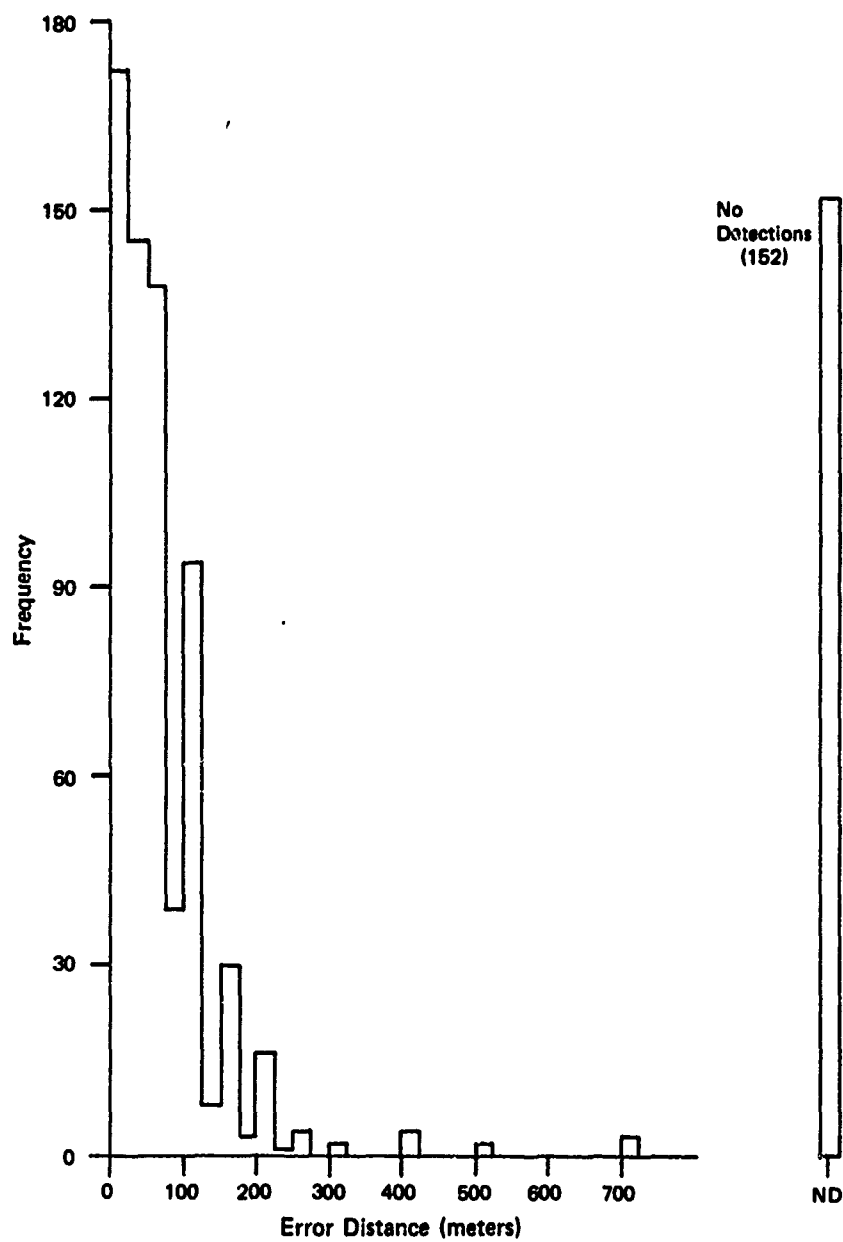


Figure 8

Table 2
Range Estimation

Condition	Number of Observations	Number of Detections ^a	Percent Detections	\bar{X} Error (meters)	SD (meters)
Overall	810	657	81.1	59.6	77.4
Terrain					
Low	270	259	95.9	64.4	98.9
Medium	270	247	91.5	54.5	60.6
High	270	151	55.9	59.6	56.8
Distance (meters)					
100	270	250	92.6	38.1	44.6
200	270	260	96.3	69.9	69.2
300	270	147	54.4	77.7	116.9
Target Speed					
Walk	270	218	80.7	68.0	89.6
Slow Run	270	219	81.1	53.9	55.9
Fast Run	270	220	81.5	56.8	73.9

^aThe N s used in analyzing range estimation and detection time data are slightly different (657 vs. 641) because of a criterion for excluding data from the detection time analysis that is not related to this report. These exclusions have negligible effects on the results.

DETECTION TIMES

Over all conditions, the mean detection time (for the targets detected) was 3.8 seconds with a standard deviation of 4.4 seconds; 79.1% of the targets were detected.

Examining the effects of terrain, but over all other conditions, the mean detection time for the low terrain complexity was 2.1 seconds and the standard deviation was 1.7 seconds; 95.6% of the targets were detected. The mean detection time for the medium terrain complexity was 5.4 seconds with a standard deviation of 6.0 seconds; 87.8% of the targets were detected. The mean detection time for the high terrain complexity was 4.1 seconds with a standard deviation of 3.5 seconds; 53.7% of the targets were detected.

Examining the effects of distances, but over all other conditions, the mean detection time for 100 meters was 2.3 seconds and the standard deviation was 1.8 seconds; 90.4% of the targets were detected. For 200 meters, the mean detection time was 3.5 seconds with a standard deviation of 3.8 seconds; 93.3% of the targets were detected. For 300 meters, the mean detection time was 6.6 seconds with a standard deviation of 6.5 seconds; 53.7% of the targets were detected.

Examining the effects of target speed, but over all other conditions the mean detection time for walking (1.5 meters/second) was 5.4 seconds with a standard deviation of 6.4 seconds; 80.0% of the targets were detected. For slow running (2.7 meters/second), the mean detection time was 3.5 seconds with a standard deviation of 2.9 seconds; 81.1% of the targets were detected. For fast running (7.5 meters/second), the mean detection time was 2.4 seconds with a standard deviation of 1.9 seconds; 76.3% of the targets were detected.

These detection data are summarized in Table 3, in which additional subdivisions of data can be studied (e.g., the mean time for target acquisition in a low complexity terrain at 100 meters when the target moved out at a walk).

Table 3
Detection Time

Condition	Number of Observations	Number of Detections ^a	Percent Detections	\bar{X} Time (seconds)	SD (seconds)
Overall	810	641	79.1	3.8	4.4
Terrain					
Low	270	258	95.6	2.1	1.7
Medium	270	237	87.8	5.4	6.0
High	270	146	54.1	4.1	3.5
Distance (meters)					
100	270	244	90.4	2.3	1.8
200	270	252	93.3	3.5	3.8
300	270	145	53.7	6.6	6.5
Target Speed					
Walk	270	216	80.0	5.4	6.4
Slow Run	270	219	81.1	3.5	2.9
Fast Run	270	206	76.3	2.4	1.9

^aThe *N*s used in analyzing range estimation and detection time data are slightly different (667 vs. 641) because of a criterion for excluding data from the detection time analysis that is not related to this report. These exclusions have negligible effects on the results.

Detection Time Data: Analysis of Variance

When an observer was given an opportunity to detect a moving human target, the amount of time it took him to detect the target was measured. All detection times were measured from the time when the target first began moving. Each target moved for a given amount of time that was dependent upon the target's range, its initial line-of-sight position at a particular range, its perpendicular direction of movement from the initial line-of-sight position, and its speed. These times are presented in Table 4. If an observer did not detect a target during the time it was moving, the total time the target was available for detection was entered as the observer's detection time.

A repeated measurements analysis of variance (7) was performed on this set of data. The results of this analysis are reported in Table 5, and are presented graphically in Figures 9, 10, 11, and 12.

Because of circumstances related to these data, the more conservative *F* max test was used to assess significance. This test demonstrated that the within-cell variation was not homogeneous (*F* max, 3 and 29 *df* = 5.79, *p* < .01). Further tests using the *F* max statistic demonstrated that the parts of the range by subjects within groups interaction, the speed by subjects within groups interaction, and the speed-range by subjects within groups interaction were not homogeneous (respectively: *F* max, 3 and 58 *df* = 7.08, *p* < .01; *F* max, 3 and 58 *df* = 3.92, *p* < .01; and *F* max, 3 and 116 *df* = 3.25, *p* < .01). Taken together, the results of these tests imply that the various variance-covariance matrices were not equal. Bartlett's test of homogeneity of variance was applied to the data to determine whether the interactions with the subjects could be pooled. The results of this test indicated that the three interactions with subjects were not homogeneous (χ^2 , 2 *df* = 50.44, *p* < .01).

Table 4
Exposure Time of Targets

Distance (meters)	Initial Position	Direction	Speed (seconds)		
			Walk	Slow Run	Fast Run
100	7.5° L	L	9	5	2
	7.5° L	R	28	16	6
	0	L	18	10	4
	0	R	18	10	4
	7.5° R	L	28	16	6
	7.5° R	R	9	5	2
200	7.5° L	L	18	10	4
	7.5° L	R	55	31	11
	0	L	35	20	7
	0	R	35	20	7
	7.5° R	L	55	31	11
	7.5° R	R	18	10	4
300	7.5° L	L	26	15	6
	7.5° L	R	82	46	17
	0	L	52	29	11
	0	R	52	29	11
	7.5° R	L	82	46	17
	7.5° R	R	26	15	6

Table 5
Analysis of Variance of the Detection Time Data

Source	df	MS	F*
Terrain (T)	2	8,183	95.87*
Subjects within groups	87	85	
Range (R)	2	18,551	250.86*
T x R	4	3,878	52.44*
R x Subjects within groups	174	74	
Speed (S)	2	5,920	120.06*
T x S	4	1,301	28.39*
S x Subjects within groups	174	49	
R x S	4	3,093	69.40*
T x R x S	8	665	14.92*
RS x Subjects within groups	348	45	
Total	809		

* = <.01.

Comparison of Detection Times, by Terrain Complexity, Speed of Target, and Distance From Target to Observer

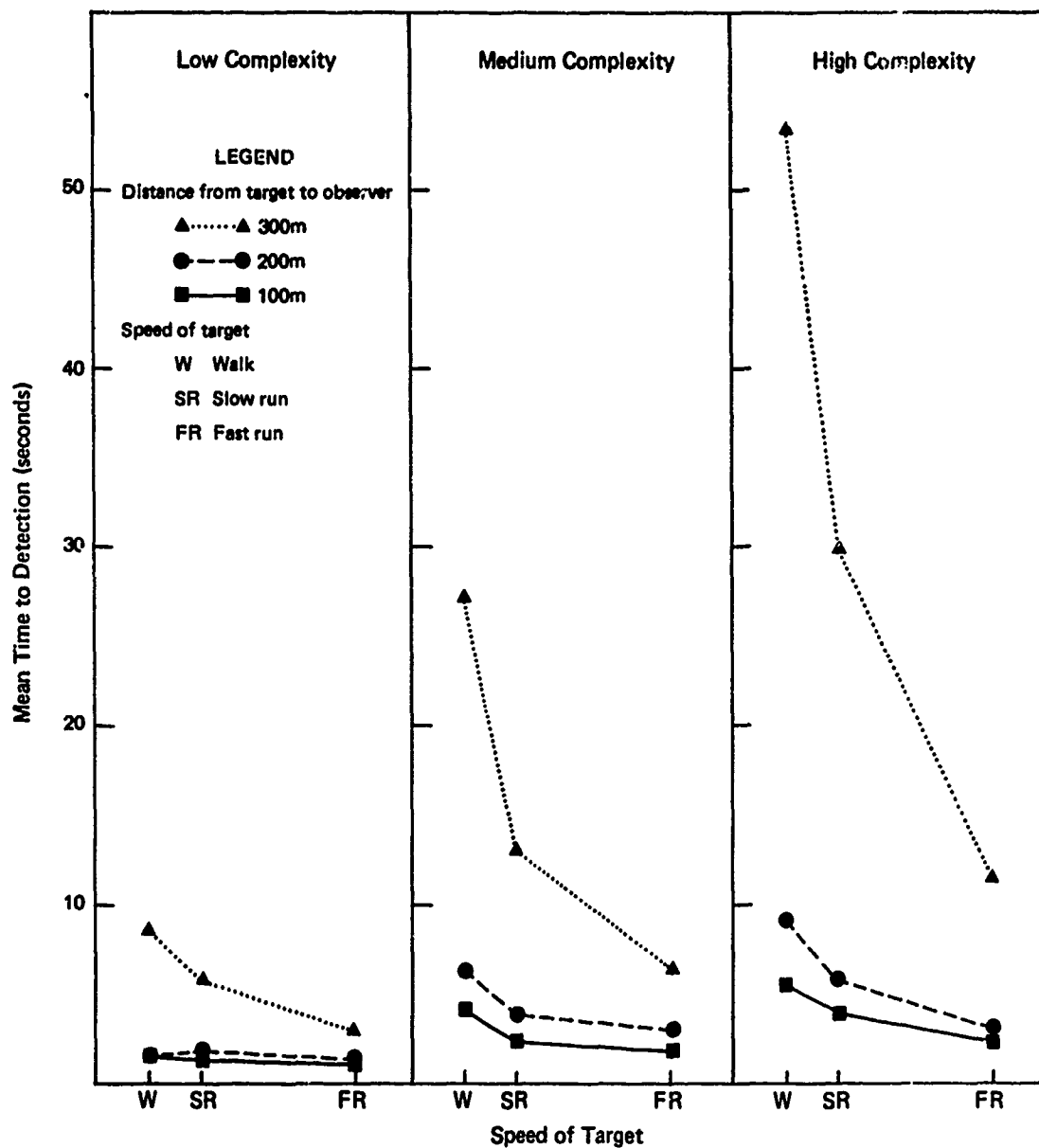


Figure 9

Comparison of Detection Times, by Terrain Complexity and Distance From Target to Observer

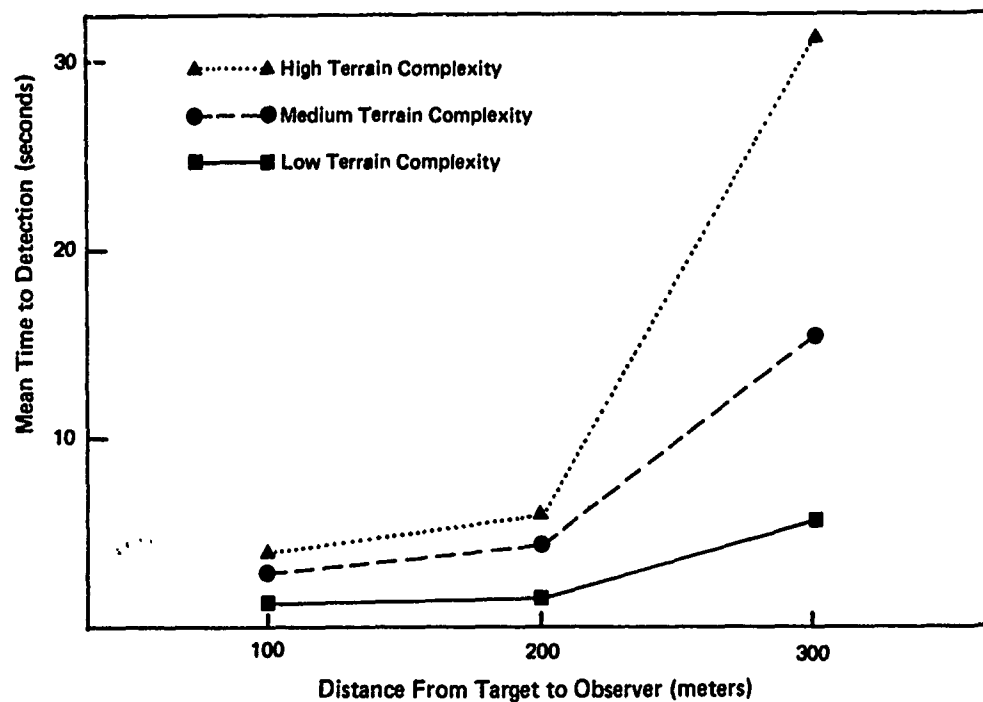


Figure 10

Comparison of Detection Times, by Terrain Complexity and Speed of Target

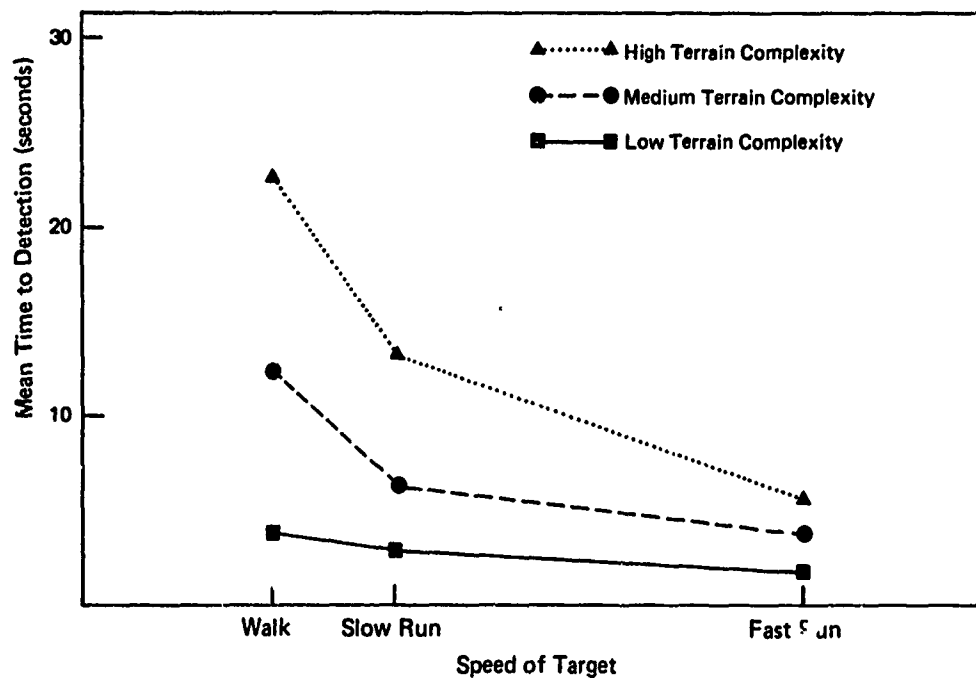


Figure 11

Comparison of Detection Times, by Speed of Target and Distance From Observer to Target

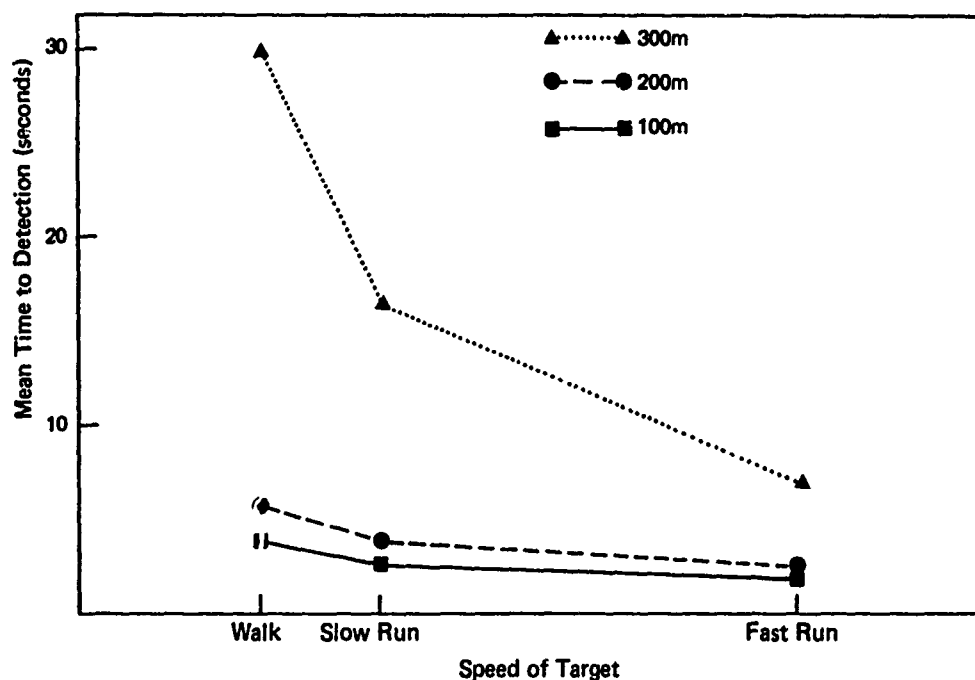


Figure 12

The results of these tests indicate that the complete repeated measurements model specified by Winer (7) was appropriate and that the conservative F tests suggested by Greenhouse and Geisser (8) should be used in determining the significance of each main effect and interaction. Application of these conservative tests showed that all main effects and all interactions were significant at the $p < .01$ level.

Detection Time Data: Analysis for Exponentiality

From the 27 ($3 \times 3 \times 3$) experimental conditions of the present experiment, 24 distributions of detection times were obtained. For the experimental conditions combining high terrain complexity and the 300-meter distance, none of the observers was able to detect the moving human target at any of the three target speeds. As a consequence, no distributions of detection times were obtained for these three experimental conditions.

A chi-square goodness-of-fit test (9) was applied to the 24 detection time distributions in order to test the hypothesis that each distribution was approximated by the negative exponential distribution

$$f(t) = \lambda e^{-\lambda t}$$

where t =time to detection, and λ =detection rate. The following procedure was used in applying the goodness-of-fit test to each detection time distribution:

(1) A maximum likelihood estimate for the parameter λ was computed using the equation

$$\lambda = N / \sum t_i \quad (1)$$

where $\hat{\lambda}$ is the estimate of λ , N is the number of detection times, and t_i is the i^{th} detection time.

(2) The distribution of detection times was divided into four intervals of equal probability when N was between 20 and 25, and into five intervals of equal probability when N was between 25 and 30. When there were four equal probability intervals, P_j (the probability that a detection fell within the j^{th} interval) was 0.25, and when there were five equal probability intervals, P_j was 0.20. Under these conditions, the expected number of detection times per equal probability interval was the same for a particular distribution, and over all distributions the expected number was always at least five.

The set of j equal probability intervals for each distribution—that is, $(0, t_1), (t_1, t_2), \dots, (t_{j-1}, t_j), \dots, (t_{j-1}, \infty)$ —was established by calculating

$$t_j = \ln [1 - (j \times P_j)] / -\hat{\lambda} \quad j = 1, 2, \dots, (j-1) \quad (2)$$

where t_j is the upper limit of the j^{th} interval, P_j is the probability that a detection time fell within the j^{th} interval, $\hat{\lambda}$ is the maximum likelihood estimate of λ for the distribution of detection times, and j is the number of equal probability intervals into which the interval was divided. For example, a distribution of detection times with $N = 30$ would be divided into $j = 5$ intervals, and P_j ($j = 1, 2, 3, 4, 5$) would be set equal to 0.20. There would be $(j-1) = (5-1) = 4$ upper time limits to be calculated, that is, t_1, t_2, t_3 , and t_4 . These upper limits would be calculated in the following manner:

$$\begin{aligned} t_1 &= \ln [1 - (1) (.20)] / -\hat{\lambda} \\ t_2 &= \ln [1 - (2) (.20)] / -\hat{\lambda} \\ t_3 &= \ln [1 - (3) (.20)] / -\hat{\lambda} \\ t_4 &= \ln [1 - (4) (.20)] / -\hat{\lambda} \end{aligned}$$

(3) The number of detection times that fell into each equal probability interval was determined and the chi-square statistic

$$\chi^2 = \sum_{j=1}^j \frac{(O_j - E_j)^2}{E_j} \quad (3)$$

with $(j-2)$ degrees of freedom was calculated, where O_j is the observed number of detection times that fell within the j^{th} interval and E_j is the expected number of detection times for the j^{th} interval.

(4) From a table of critical values of the chi-square distribution for a specified rejection rate, α , a critical value for the chi-square distribution was obtained and compared with the computed value of the chi-square statistic. If the computed chi-square statistic was greater than the tabled critical value, the hypothesis that the distribution of detection times was exponential was rejected. If the computed chi-square statistic was less than the critical value, the hypothesis that the detection times were distributed exponentially was not rejected.

The above procedure was applied to the 24 detection time distributions. (For distribution of detection times see Appendix F.) The results of these goodness-of-fit tests are presented in Table 6. Using a powerful criterion of rejection, $\alpha = .10$, led to the rejection of the hypothesis of exponentiality in 22 of the 24 cases, or 91.6% of the time. Using a less powerful criterion of rejection, $\alpha = .01$, led to the rejection of the exponentiality hypothesis in 13 of the 24 cases, or 54.2% of the time.

Table 6
Exponentiality of Detection Times^a

Terrain Complexity	Distance (meters)	Speed ^b								
		Walk			Slow Run			Fast Run		
		N	χ^2	df	N	χ^2	df	N	χ^2	df
Low	100	30	28.01***	3	30	26.34***	3	30	31.68***	3
	200	30	25.01***	3	30	10.68**	3	28	33.07***	3
	300	26	15.73***	3	26	22.46***	3	28	13.79***	3
Medium	100	30	12.34***	3	30	38.34***	3	27	17.06***	3
	200	29	9.52**	3	30	7.35*	3	26	3.61	3
	300	20	6.80**	2	24	9.34***	2	21	4.71*	2
High	100	24	7.68**	2	23	6.47**	2	20	32.80***	2
	200	27	1.97	3	26	10.16**	3	26	10.15**	3
	300	--	--	--	--	--	--	--	--	--

^aThe data show computed chi-square statistics for the goodness-of-fit test of the exponentiality of the 24 detection time distributions.

^b* = $p < .10$; ** = $p < .05$; *** = $p < .01$.

DISCUSSION

RANGE ESTIMATION

Informal doctrine specifies that errors in range estimation should be no greater than plus-or-minus 10%. The data reported in the Results section show that, over all conditions, the average error deviates from the prescribed limits for errors. On the average, under the conditions of this experiment, the ability to estimate distances is inadequate.³

The data show another salient aspect of range estimation. They tend to support the following concept: As range increases, accuracy (inverse of average error) and precision (inverse of variance) decreases. That is, as distance increases, not only are there greater errors in estimating, but there is also an increase in the scatter of the estimates. This concept is reflected in the large differences between average errors and standard deviations when compared across distances.

PERCENTAGE OF DETECTIONS

Only 81.1% of the targets were detected. However, it must be noted that a large block of the no-detections was concentrated in the trials at 300 meters on the high complexity terrain. These trials made up 11.1% of the total trials (90 out of 810), and there were zero detections in these trials; the target simply was not visible.

³The results are being studied further in Work Unit DETECT to determine their reliability and generality. If the discrepancy between informal doctrine and actual range estimation performance, reported in the present study, proves to be a reliable phenomenon, then serious consideration should be given to establishing formal doctrine and changing procedures for training in range estimation.

The remaining 9.9% recorded as no-detection trials occurred where the target was visible but was not detected by the subject. The effects of terrain upon percentage of targets detected tended to be what is commonly expected: As terrain becomes more difficult, the percentage of detections drops off.

ANALYSIS OF DETECTION TIMES

The results of the analysis of variance of the observers' detection times showed that the ability of the combat-naïve soldier to detect human targets is significantly affected by the target's speed, its distance from the observer and the complexity of the background in which the target appears. As the terrains investigated became more complex, or as the magnitude of the target-to-observer range increased, the magnitude of the detection times increased; but, as the target's speed increased, direction times *decreased* in magnitude. Therefore, terrain complexity and target range were positively related with the time to detection, while target speed was negatively related with the time to detection.

These results suggest that the actual underlying probability distribution of the detection time data collected in the present experiment is more likely to be a complex distribution composed of many simpler distributions, rather than one simple distribution.

Considering the interaction of the effects of target range and target speed upon detection times, it can be seen in Figure 12 that (a) as the target's speed increased, the time to detection decreased for each level of the range variable; (b) as the target-to-observer range increased, the time to detection increased for each level of the speed variable; (c) as the target's speed increased, the time to detection decreased more rapidly for targets at 300 meters than for targets at either 100 or 200 meters. The range x speed interaction indicates that target speed has its greatest effect upon the detection of more distant targets and less of an effect upon the detection of nearer targets.

However, the form the range x speed interaction took depended upon the terrain in which the target appeared (Figure 9). For targets appearing in the low complexity terrain, the range x speed interaction was less well developed than for targets appearing in the high complexity terrain. This result suggests that the terrain in which a target appears affects the extent to which an observer's detection ability for targets at a particular range is influenced by target speed.

The terrain x range x speed interaction may be explained in terms of static and dynamic target-background distinction:

Static. When terrain complexity is low, *target-background distinctiveness* is greater for nearer targets than for distant targets. As terrain complexity increases, the target-background distinction decreases for *both* near and far targets (with far targets showing the least target-background distinctiveness). This explanation is not unreasonable since, as the terrain becomes more complex, there is an increase both in the total number of forms in the background and in the number of forms in the terrain with curvatures like the target.

Dynamic. At low speeds, the target ruptures the continuity of the background less than at faster speeds. Thus, at low speeds, target-background distinctiveness would be less than at higher speeds. At any reasonable speed, nearer targets appearing in low complexity terrains are readily distinguishable from the background and detection is rapid. At the slower speeds, more distant targets in low complexity terrains are less distinguishable from the background and detection is slow. At the higher speeds, the rate of rupture of the background is increased, and detection is more rapid.

As the terrains increase in complexity, target-background distinctiveness decreases for all slow-moving targets at both near and far distances, with distinctiveness being least at the far target ranges. Detection there is slow. As the target speed is

increased, target-background distinctiveness increases because of an increasing rate of rupture of the background texture, and detection becomes more rapid. Finally, in a case where there is no opportunity for a target-background relationship to develop (i.e., when the target is completely occluded by the background), no detection ever occurs.

The conceptualization of detection times varying as a function of static and dynamic target-background distinction will be tested in future research that will study the effects of visibility, contrast, and image intensifiers.

ANALYSIS FOR EXPONENTIALITY OF DETECTION TIME DATA

The results of the goodness-of-fit tests of the 24 detection time distributions showed that, under the most powerful criterion, 91.6% of the time the hypothesis of exponentiality was rejected. Under the least powerful criterion, the exponentiality hypothesis was rejected 54.2% of the time. These results suggest that the underlying probability distribution for the detection time distributions obtained in the present study was not exponential in form. As a consequence, it would appear that the Tank Weapons System model of detection is not appropriate for the detection of human moving targets.

Inspection of the detection time distributions revealed that these distributions tended to be positively skewed and, therefore, not normal. Winer (7) suggests that such distributions often can be normalized by the application of a logarithmic transformation. Distributions that can be normalized through the use of a logarithmic transformation would, of course, be lognormal. As a consequence, in future research, it may be useful to explore the possibility that the distributions of detection times collected in the present study were lognormal.

**LITERATURE CITED
AND
APPENDICES**

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3. Stollmack, S. "Detection Time Data Analysis," Chapters 1-3 in D. Howland and G. Clark (eds.) *The Tank Weapon System*, vol. 2, Report No. RF-573 AR 66-2, Ohio State University Systems Research Group, December 1966.
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- Brown, Paul. "Application of the Negative Exponential Model to Detection Time Distributions for Military Targets in Natural Terrain Background," thesis published by Ohio State University, 1966.
- Gordon, D.A. and Lee, G.B. *Model Simulator Studies. Visibility of Military Targets as Related to Illuminant Position*, Project Michigan, Willow Run Laboratories, 21440341-T.
- Louis, Nicholas B. *The Effects of Observer Location and Viewing Method on Target Detection with the 18-inch Tank-Mounted Searchlight*. HumRRO Technical Report 91, June 1964.
- Nichols, Thomas F. and Powers, Theodore R. *Moonlight and Night Visibility*. HumRRO Research Memorandum, January 1964.
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Taylor, John E. *Identification of Stationary Human Targets*, HumRRO Research Memorandum, December 1960.

Weasner, M.H. and Carlock, J. *Smoke Marker Detection and Identification*. Picatinny Arsenal, Dover, New Jersey, August 1965.

Wolff, Peter C., Burnstein, David D., and Van Loo, Joseph A. *Target Detection: Study 6, The Effects of Schedules of Collective Reinforcement on a Class During Training in Target Detection*, HumRRO Research Memorandum, July 1962.

Wolff, Peter C. and Van Loo, Joseph A. *Target Detection: Study 3, The Relative Usefulness of Active Participation and Verbal Description Techniques in Target Training*, HumRRO Research Memorandum, July 1962.

Wolff, Peter C., Van Loo, Joseph A., and Burnstein, David D. *Target Detection: Study 7, Partial Point-Out of Targets as Collective Reinforcement in Group Target Detection Training*, HumRRO Research Memorandum, August 1962.

Appendix A

SELECTED ANNOTATED BIBLIOGRAPHY

Brown, Paul. "Application of the Negative Exponential Model to Detection Time Distributions for Military Targets in Natural Terrain Background," thesis published by Ohio State University, 1966.

The dependent variable was the subject's target detection time measured from when the target was fully exposed until the subject detected the target. The independent variables were range to target, a measure of terrain complexity, angular velocity of the target with respect to subject, and the plane angle between lines of sight from the observer to the target scene. From detection time data obtained in a laboratory situation, estimates of λ were computed, using the method of maximum likelihood. The laboratory estimate of λ was then related to physical measurements obtained in the field on speed, contrast, crossing velocity, and terrain complexity.

Dobbins, D.A. et al. *Jungle Vision II: Effects of Distance, Horizontal Placement, and Site on Personnel Detection in an Evergreen Rainforest*, U.S. Army Tropic Test Center, Fort Clayton, Canal Zone, March 1965.

The dependent variables were detection threshold (that distance at which a target is detected 50% of the time), distance estimation, and detection time. The independent variables were target distance, horizontal target placement, and site selection. The detection threshold for each subject was correlated with the level of illumination present on the site before and after this test, using a Pearson product-moment correlation (r).

Dobbins, D.A. and Kinderk, C.M. *Jungle Vision V: Evaluation of Three Types of Lenses as Aids to Personnel Detection in a Semideciduous Tropical Forest*, U.S. Army Test Evaluation Center, Fort Clayton, Canal Zone, July 1965.

The dependent variables were 50% detection thresholds (the distance that a target is detected on 50% of the trials), distance estimation of detected targets, and search time required to detect a target. The independent variables were mode of observation (lenses vs. unaided vision), horizontal target placement (5 radii) in subject's field of search (180°), and eight target distances (30' - 115') along each radius. Descriptive statistics and analysis of variance are reported.

Gordon, D.A. and Lee, G.B. *Model Simulator Studies. Visibility of Military Targets as Related to Illuminant Position*, Project Michigan, Willow Run Laboratories, 21440341-T.

Dependent variables were threshold for detection, and class and category identification in terms of distance (feet) from target. Independent variables were illumination, position of illuminant relative to target, target class and target category, and field position of the target. Descriptive statistics were used.

Louis, Nicholas B. *The Effects of Observer Location and Viewing Method on Target Detection with the 18-inch Tank-Mounted Searchlight*, HumRRO Technical Report 91, June 1964.

The dependent variables were the number of targets detected, the number of correctly identified targets, the time required for target detection, and the time and accuracy of sighting-in target. The independent variables were the viewing method, distance of subject from searchlight along a line at approximately a right angle (85°) to the angle of the beam, distance of target from the searchlight, and the types of targets used. Descriptive statistics and "probability of detection" percentages are reported.

Nichols, Thomas F. and Powers, Theodore R. *Moonlight and Night Visibility*, HumRRO Research Memorandum, January 1964.

This paper presents a literature survey of six field experiments conducted under night visibility.

Olsen, Howard C., Gross, Albert E., and Voiers, William D. *Recognition of Vehicles by Observers Looking Into a Searchlight Beam*, HumRRO Technical Report 49, July 1958.

The dependent variable was the detection and recognition of tank-sized vehicles. The independent variables were distance of searchlight from subject line, whether or not subjects were looking into a searchlight, position of subjects in relation to center of beam, and paths of approach of vehicle toward subject. Descriptive statistics are reported.

Strauss, P.S. and DeTogni, G.R. *Personnel Target Acquisition Under Flare Illumination*, Picatinny Arsenal, Technical Report 3012, July 1962.

The dependent variables were target detection and identification. The independent variables were amount of illumination, burning time, target size, target location, and target distance from the flare. Descriptive statistics are reported.

Taylor, John E. *Identification of Stationary Human Targets*, HumRRO Research Memorandum, December 1960.

The dependent variables were detection and identification of the target. The independent variables were position of the target, position of the subject, type of night vision training administered to each group, and whether the moon was present or not. Descriptive statistics are reported.

Weasner, M.H. and Carlock, J. *Smoke Marker Detection and Identification*, Picatinny Arsenal, Dover, New Jersey, August 1965.

The dependent variables were detection, location, and identification. The independent variables were volume, color, and location of smoke grades. Descriptive statistics are reported.

Wolff, Peter C., Burnstein, David D., and Van Loo, Joseph A. *Target Detection: Study 6, The Effects of Schedules of Collective Reinforcement on a Class During Training in Target Detection*, HumRRO Research Memorandum, July 1962.

The dependent variables were the number of correct target detections and the number of correct "no-target" detections. The independent variables were the number of slides shown, sequence for presenting slide material, and verbal praise. Descriptive statistics and an analysis of variance are reported.

Wolff, Peter C. and Van Loo, Joseph. *Target Detection: Study 3, The Relative Usefulness of Active Participation and Verbal Description Techniques in Target Training*, HumRRO Research Memorandum, July 1962.

The dependent variables were the number of correct detections, the number of correct "no-target" responses, number of correct verbal identifications of targets detected, and the number of false detections and no responses. The independent variables were the variations in training methods. Descriptive statistics and an analysis of variance are presented.

Wolff, Peter C., Van Loo, Joseph A., and Burnstein, David D. *Target Detection: Study 7, Partial Point-Out Targets as Collective Reinforcement in Group Target Detection Training*, HumRRO Research Memorandum, August 1962.

The dependent variables were the number of correct target detections and the number of correct "no target" responses. The independent variables were the total number of slides shown and the collective reinforcement administered on the basis of the number of correct detections made by the group during training periods. Descriptive statistics and analysis of variance are reported.

Appendix B
BIOGRAPHICAL INFORMATION SHEET

Subject Number _____

Name _____
 Last First Middle Initial

Rank _____

Social Security Number _____

Age _____ Years in Service _____

Experience — Basic Training _____
 Advanced Infantry Training _____
 NCOC Program _____
 OCS Program _____
 Combat _____

Previous Assignments — Germany _____
 Korea _____
 USA _____
 Vietnam _____
 Other _____ (please specify)

Appendix C

PROCEDURE OF ORIENTING SUBJECTS TO THE EXPERIMENT

Have subjects sit in AREA A and hand out to each of them the following materials (1) one pencil, (2) one biographical information form. Read to them the following instructions:

"Today you are to participate in a target detection experiment. Before we begin the experiment, I would like for you to fill out the biographical information form you have been given. Write your name in the space marked 'Name', last name first, followed by your first name and middle initial. Next in the appropriate blanks indicate your rank, social security number, and age. Under the experience category indicate with an 'X' if you have had basic training, advanced infantry training, NCOC training, or OCS training. Under previous assignment category indicate with an 'X' if you have had assignments in Germany, Korea, the United States, or Vietnam."

Now give the subjects sufficient time to fill out their biographical information forms. After the forms have been filled out, read to the subjects these instructions:

"You are to participate in an experiment which will measure your ability to detect moving human targets and to estimate the range at which these targets appear. Throughout the experiment you are to imagine that you are in a defensive position. You are to search for moving targets in the sector that will be indicated to you by the experimenter at the observation point. This sector is a section of a circle. Targets will appear only in this sector so at all times keep your eyes in this general area. Are there any questions at this point?" (Answer questions, then continue with instructions.)

"When I finish reading the instructions, you will each go, one at a time, to the observation point. You will note that at the top of your biographical information form in the space marked 'Subject Number' that there is a number. This will be your number for the duration of this experiment. When the NCO in charge calls your number, you are to go to the observation point which is located there (INDICATE WHERE THE OBSERVATION POINT IS LOCATED). When you arrive at the observation point, you are to hand to the experimenter at the point your pencil and biographical information form. The experimenter will indicate to you where you are to stand and the sector you are to search. Also he will give to you a hand switch like the one I am holding in my hand (SHOW HAND SWITCH). You are to hold this switch in the hand you normally write with like I am doing now (SHOW HOW TO HOLD THE SWITCH). When you see a target press the switch like this (SHOW HOW TO PRESS THE SWITCH). When you press the switch this will cause a timer to stop and this will tell the experimenter how long it took you to detect the target. Are there any questions at this point?" (Answer any questions, then continue with the instructions.)

"After you report to the experimenter you have detected the target by pressing the hand switch you are holding, the experimenter will ask you to tell him at what range you first saw the target appear. Estimate this range to the nearest 5 meters. You will have an opportunity to detect 9 moving targets and estimate 9 ranges. After you detect a target and estimate its range you are to turn around 180° so you will be facing away from the sector of search. On command you are to turn around, face the sector of search and begin searching for the next target. After you have had an opportunity to detect 9 targets and estimate their ranges you will be asked to move to a position

(AREA B) indicated by the experimenter at the observation point. You will wait at this point until all of your group has completed the experiment. Are there any questions?" (Answer questions, then send first subject to the observation point.)

Movement of subjects to the observation point:

Send subjects to the observation point one at a time. The experimenter at the observation point will indicate to you when he is ready for a new subject by shouting to you to send out a new subject. Have your NCO select a man to go each time. Have the NCO keep the men quiet. The men may smoke if they wish.

Movement of subjects to AREA B:

Have the NCO at this point keep the men quiet and keep them seated. The men may smoke if they wish.

Appendix D
SUBJECT DATA SHEET

Subject Number _____

Name _____

Social Security Number _____

<u>Trial</u>	<u>Observation to be Made</u>	<u>Detection Time</u>	<u>Range Estimate</u>
1	_____	_____	_____
2	_____	_____	_____
3	_____	_____	_____
4	_____	_____	_____
5	_____	_____	_____
6	_____	_____	_____
7	_____	_____	_____
8	_____	_____	_____
9	_____	_____	_____

Appendix E
TERRAIN COMPLEXITY DATA SHEET

1	2	3	4	5	6	7
Very Easy To Detect	Easy To Detect	Moderately Easy To Detect	Moderately Difficult To Detect	Difficult To Detect	Very Difficult To Detect	Impossible To Detect

Name _____

Social Security Number _____

Appendix F

DISTRIBUTION OF DETECTION TIMES

This Appendix is a visual aid representing the distribution of detection times. Figure F-1 shows the distribution of detection times over all conditions and is followed by nine graphs depicting the distribution for each of the independent variables.

The abscissa on each of the graphs is marked at each half-second. Also shown on the far right is a block that represents the number of no detections.

For ease of comparison, the scales for Figures F-2 through -10 are the same.

Distributions of Detection Times Over All Conditions

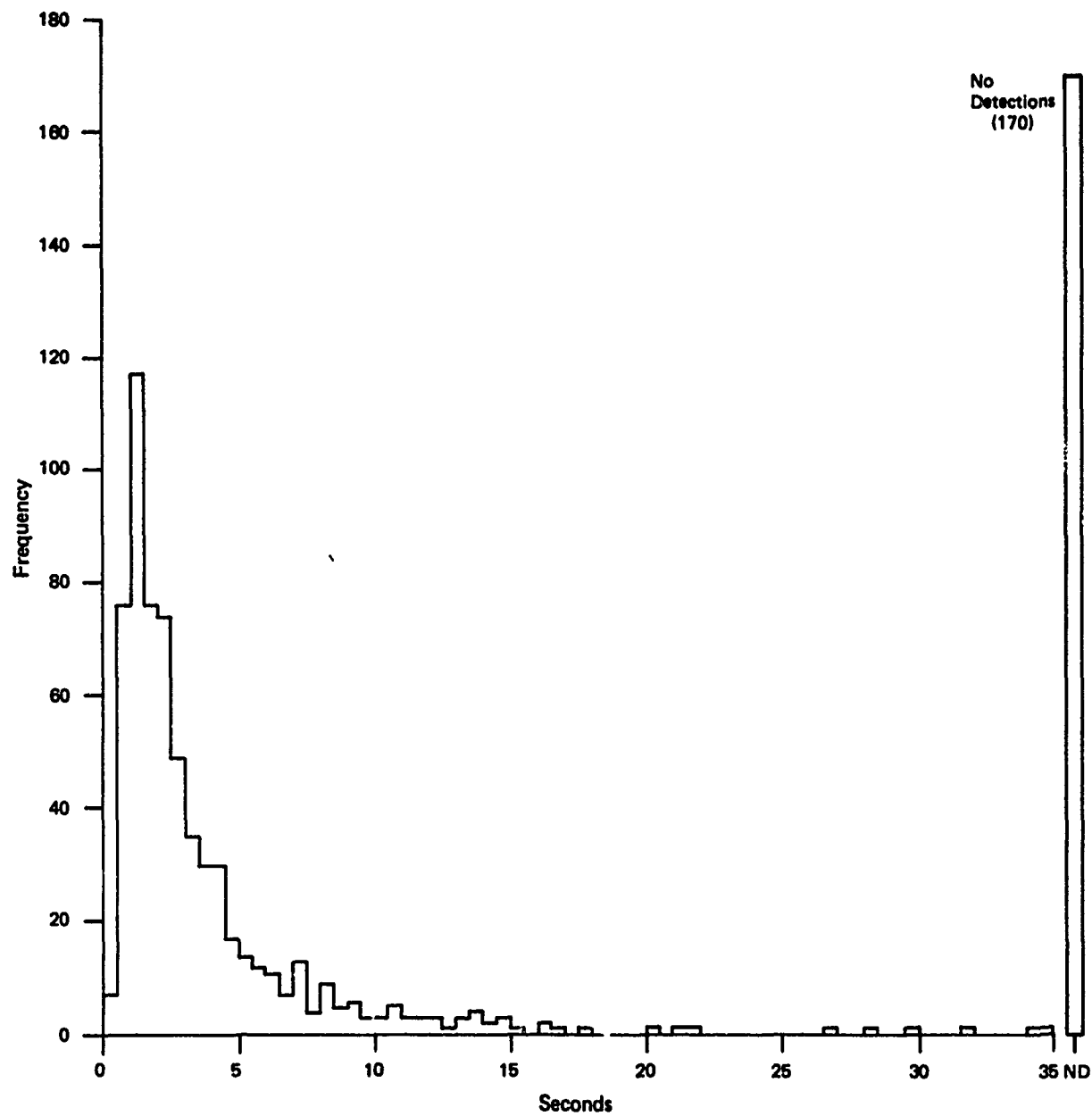


Figure F-1

Distribution of All Detection Times on the Low Complexity Terrain

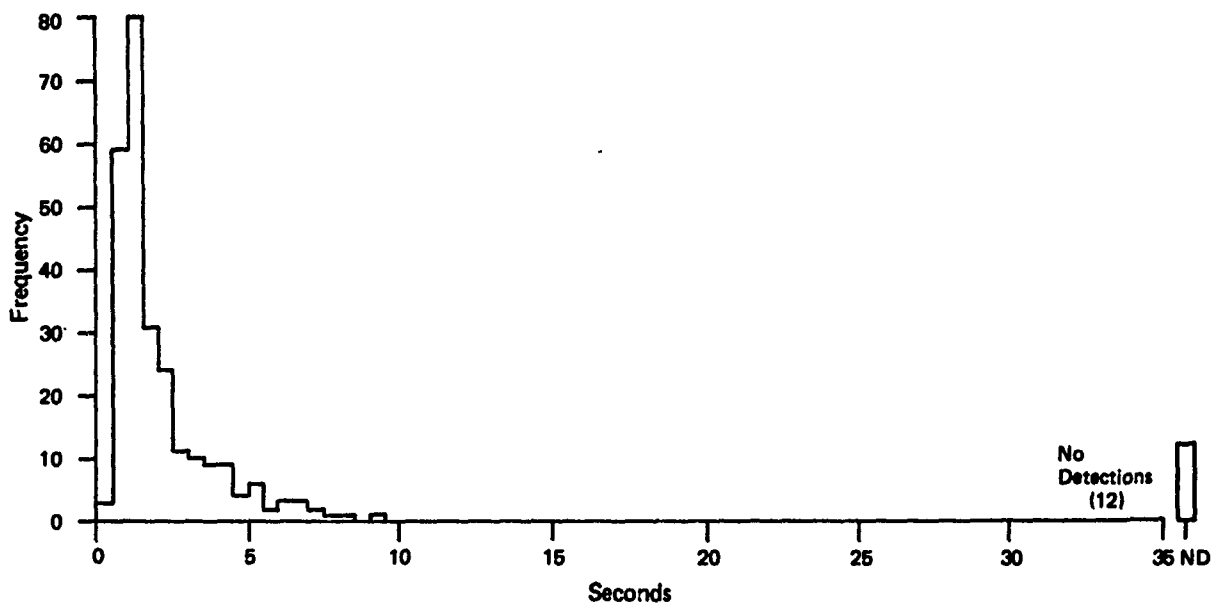


Figure F-2

Distribution of All Detection Times on the Medium Complexity Terrain

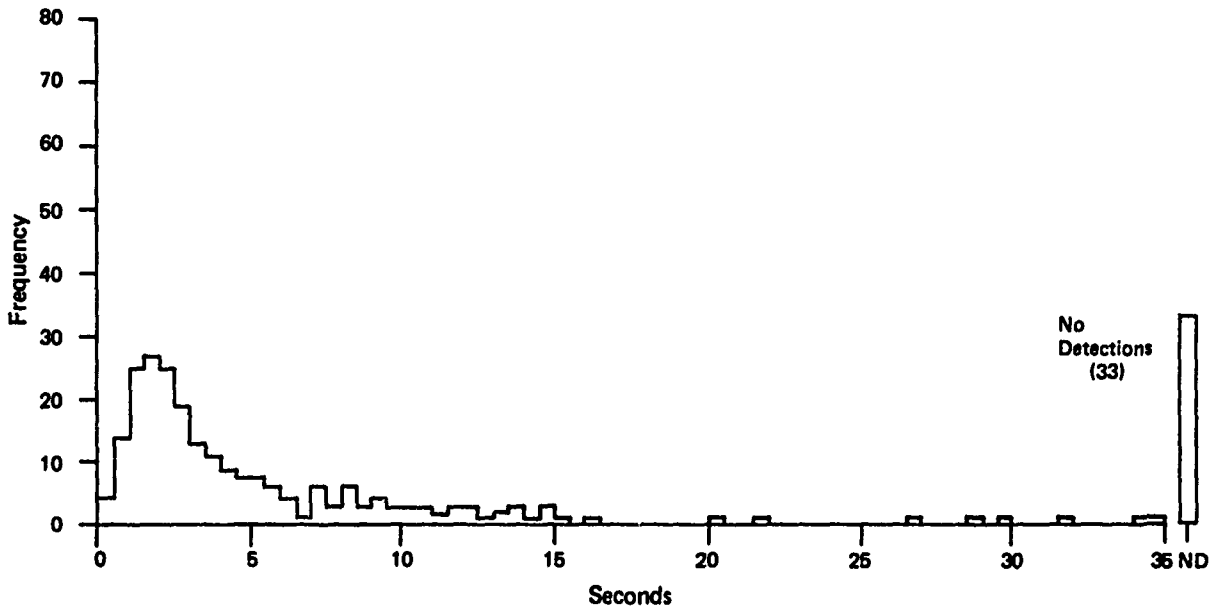


Figure F-3

Distribution of All Detection Times on the High Complexity Terrain

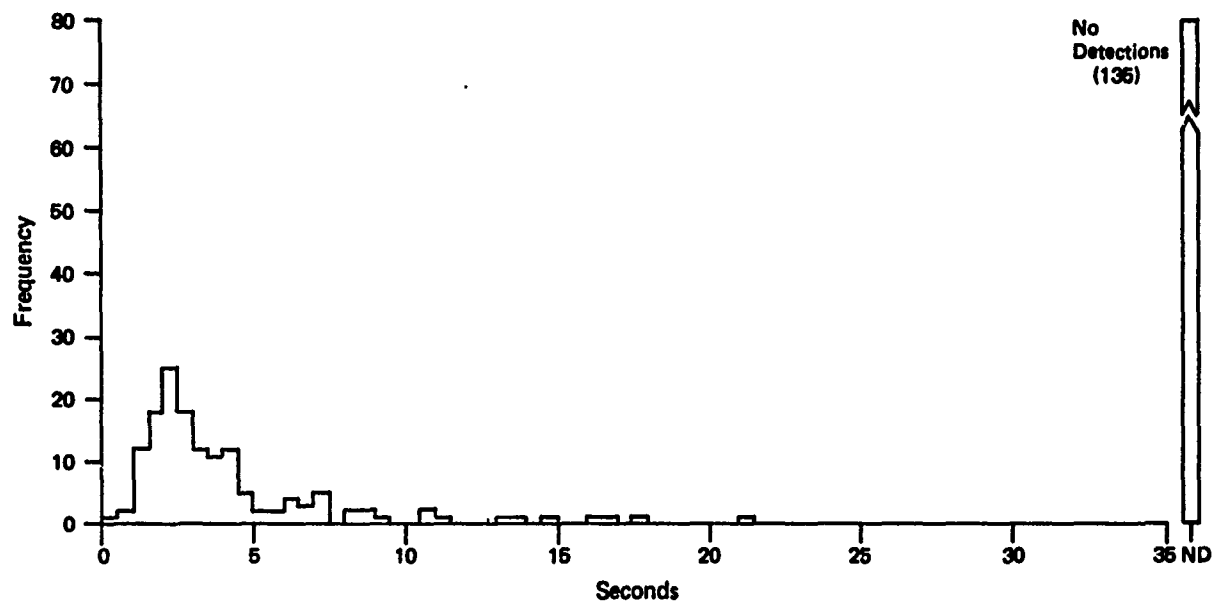


Figure F-4

Distribution of All Detection Times for the 100-Meter Target

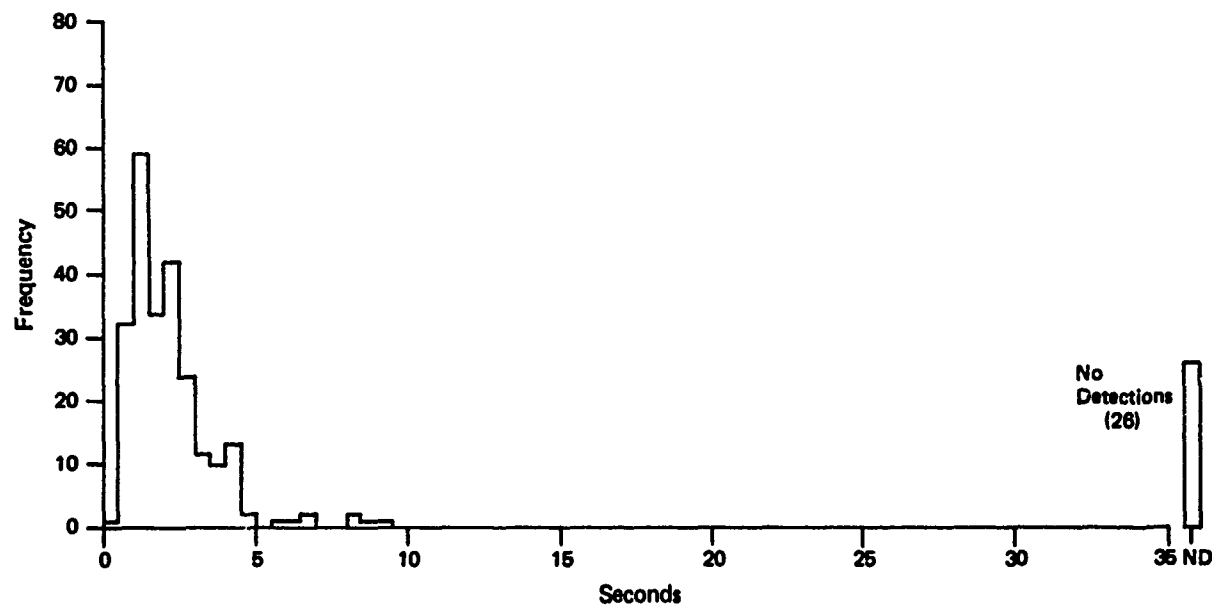


Figure F-5

Distribution of All Detection Times for the 200-Meter Target

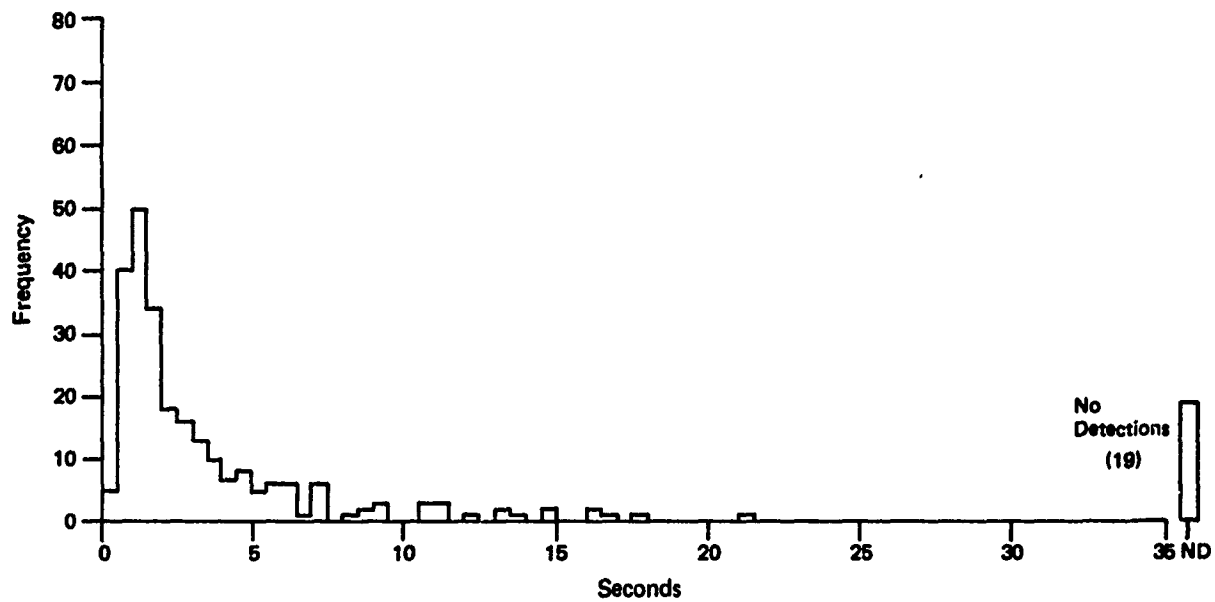


Figure F-6

Distribution of All Detection Times for the 300-Meter Target

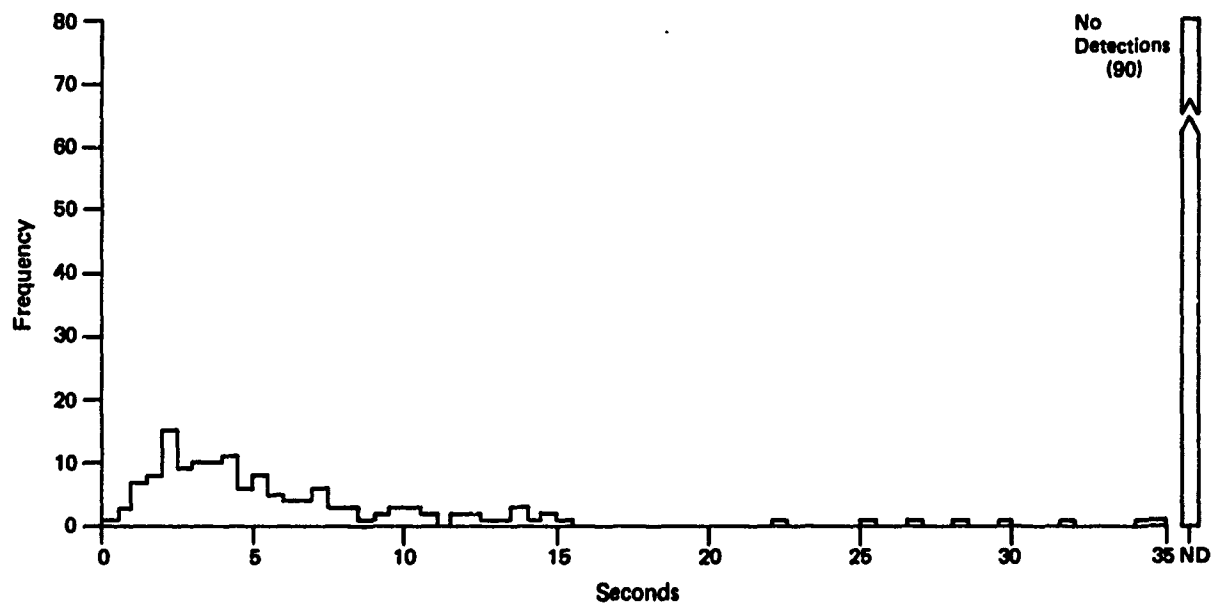


Figure F-7

Distribution of Detection Times for Target Speed: Walk

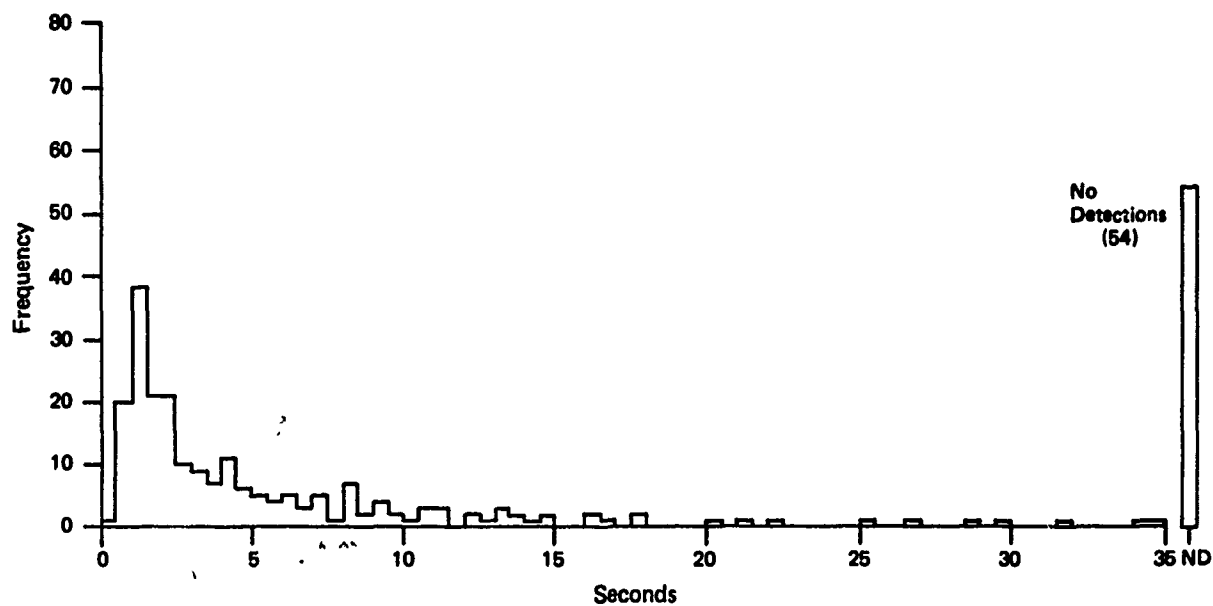


Figure F-8

Distribution of Detection Times for Target Speed: Slow Run

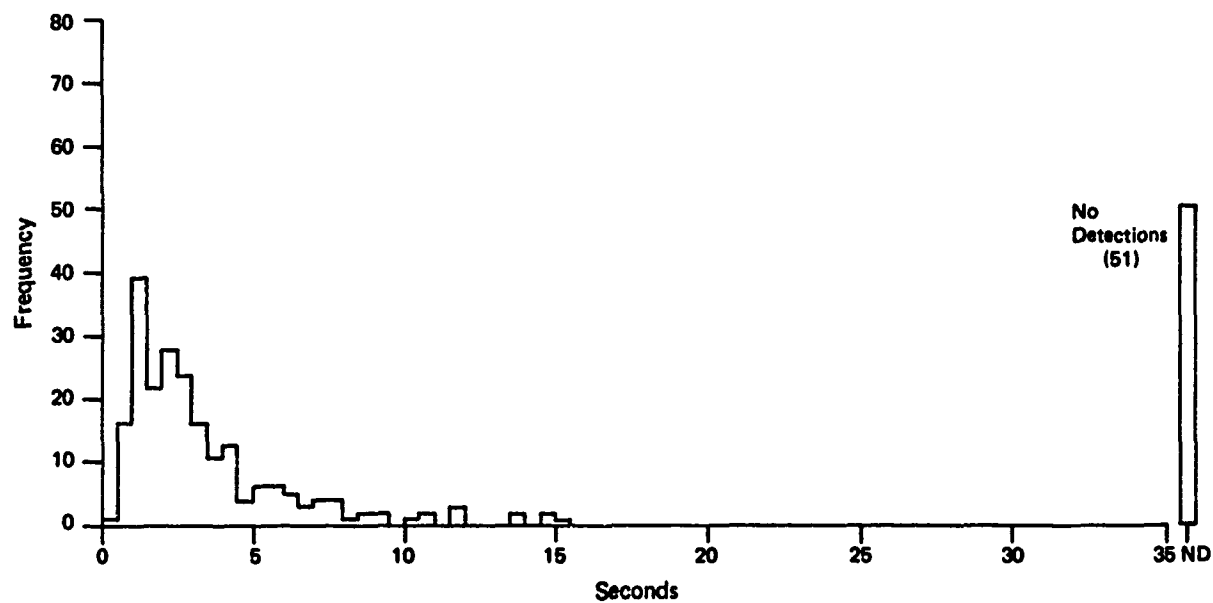


Figure F-9

Distribution of Detection Times for Target Speed: Fast Run

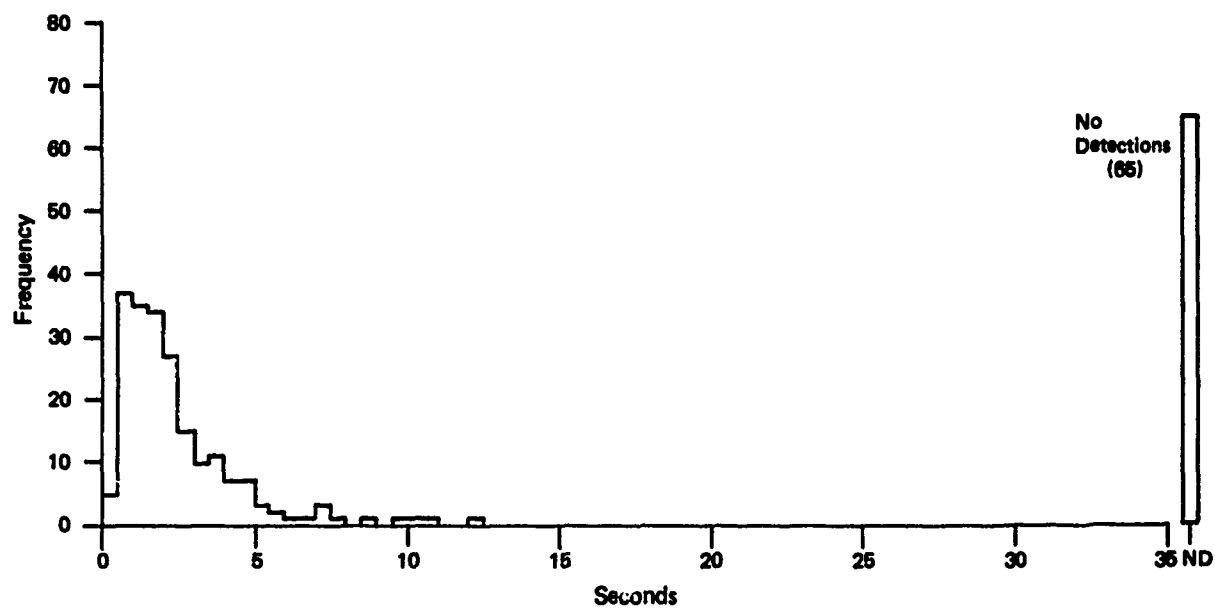


Figure F-10